unfavourable, points being noticed. The object of this paper is, by calling forth a discussion on the subject generally, but more particularly to the points above noticed, to lead to further information being obtained, and a clearing up of all difficulties. Some of the difficulties can, doubtless, be easily explained when the key is once given; but at present the key is wanting, and, in consequence, the scheme proposed in the essay *now appears* very incomplete. If I can be shown to have misrepresented the essayists, I shall be glad to correct my remarks. Some of the defects pointed out in this paper could be removed simply by an addition to the estimated cost of the works; but to get rid of others would involve material modifications of the scheme proposed in the essay. A satisfactory and efficient scheme will be devised only when there appears a decided wish on the part of the public to have one, and a determination to overcome the difficulties which are now in the way. It is to be hoped, therefore, that the discussion now invited will serve to keep public interest alive to the importance of the subject.

On the Sea-cell as a Possible Source of Danger in Torpedo Experiments.

By H. Moors, Esq.

[Read 13th October, 1881.]

One of the results of the late unfortunate accident at Queenscliff, whereby a boat's crew was destroyed through the premature explosion of a torpedo, has been to bring into considerable prominence the current from what is known as the sea-cell, and the possibility of its being a source of danger in torpedo experiments. When the cause of the accident was being keenly discussed by all who were interested in or conversant with the subject of electricity, the sea-cell current was naturally spoken of, and this was more particularly the case after it had been satisfactorily established by the Board appointed to inquire into the circumstances of the accident that the explosion did not occur through an accidental contact through or by means of the firing key.

A casual conversation with the President of this Society induced me to give some attention to the sea-cell current as a possible cause of the accident, and at his request I embodied the results in a memorandum which the Board published as an appendix to its report.

Now, if the reasoning in that memorandum were unsound, it could have been shown to be so; my calculations were equally open to correction. But those who have objected to my conclusions have not attempted to show that there is any fallacy in the one or the other. They have contented themselves with denying the conclusions; and some who have spoken as with authority have boldly, and, as I think, rashly, asserted that it is impossible for the explosion to have been caused by a sea-cell current.

The question, however, can hardly be considered as finally disposed of by such objectors. Mere assertion is not argument; and as the question is by no means exhausted, I have thought it desirable to bring together in this paper such considerations as seem to be salient to the subject, to view them in the light of some recent experiments, and to invite the members of this Society to give the subject a more thorough and scrutinising examination than it has hitherto met with.

In doing so I shall, of course, have to repeat the substance of the memorandum I have referred to. I have since been informed, however, that the wire used in the fatal experiment was No. 16 B.W.G., and not No. 15 B.W.G., as I had been given to understand. This has rendered necessary some slight alterations in my calculations as to lengths of wire through which fuses may be expected to explode, and I only mention the fact for the benefit of those who may be at the trouble of comparing the two documents.

It appears that the case containing the fatal charge was of zinc. Now, it is a common practice to attach the earth-wire of the charge to the metal case, which thus becomes the earth plate. I do not know whether this course was adopted in the Queenscliff experiment; but if it was not, it is easy to understand how the earth connection, though left loose, might come into contact with the zinc. And if we further assume that some portion of the copper of the firing line came into contact with the iron body of the "Cerberus," the zinc, the iron, and the sea constituted what is termed a sea-cell, and a simple test with the galvanometer will show any one who may care to make the experiment that under these circumstances a considerable current passes along the wire. The only difference between this sea-cell and a cell consisting of a tumbler of sea-water, with slips of zinc and iron, would be in their internal resistances; the electromotive force would be the same, but the internal resistance of the small cell would be considerable, while that of the sea-cell is inappreciable, and may be regarded as nothing.

It is easy to see how there *may* have been this contact between the copper wire of the firing line and the iron body of the vessel. The exposed end of the wire may, for instance, have touched some portion of the vessel, or its metal fittings, metallically connected therewith, and not originally covered with paint, or from which the paint had been removed.

But I do not say there was such a contact. Indeed, my object in this paper is not to usurp the functions of the Board by investigating the cause of the accident, but to call attention to what may prove a source of danger, and perhaps of disaster, in similar experiments, conducted under similar circumstances.

The important question, therefore, is, whether the electrical action of a sea-cell composed of a zinc case like that used in the fatal experiment, the body of an iron vessel, and the sea-water in or on which both are lying, is sufficient to produce a current equal to or approaching within dangerous proximity to that which is known to be sufficient to explode an ordinary fuse.

By the well-known law called Ohm's law, the electromotive force in any circuit, measured in Volts divided by the current circulating in the circuit, measured in Vebers, is equal to the total resistance of the circuit, measured in Ohms. Given any two of these quantities, and the third can at once be ascertained.

Poggendorff (as quoted by Sabine) gives the electromotive force of zinc and iron in a concentrated solution of chloride of sodium (common salt) as—

$$\begin{aligned} & \cdot 476 \text{ of a Daniell's element,} \\ = & \cdot 476 \times 1 \cdot 079 \text{ Volt,} \\ = & \cdot 514 \text{ Volt.} \end{aligned}$$

From tabulated results obtained by Professors Ayrton and Perry, and given in Everett's *Units and Physical Constants,* the value would appear to be ·564. It is found thus:—

Difference of potential between copper of wire and iron	=	− ·146
,, ,, ,, iron and sea-water	=	− ·605
,, ,, ,, sea-water and zinc	=	·565
,, ,, ,, zinc and copper of wire	=	·750
Total	=	·564

The latter is probably the more reliable authority, and it is certain that the electromotive forces of the more generally known forms of cells, as calculated from Ayrton and Perry's results, agree with those which, from other measurements, we know to be correct.

The first and fourth of these differences of potential are for contacts in air. I do not know what difference, if any, there would be for contacts in sea-water. In the case of the accident, one of these contacts was probably in air; the other may have been either.

The detonating fuse usually made use of for submarine purposes is that numbered 12 in the table given in the *Chatham Instructions in Military Engineering.* It consists of a bridge of ·3 inch of fine platinum wire, the resistance of which, when cold, is ·325 Ohm; at the fusing point, ·74 Ohm; and the current sufficient to fire a charge through it, ·75 Veber. A more sensitive detonator (No. 13) is sometimes used for land service. It is made of finer wire, and its resistance, when cold, is about 1·08 Ohm; at the fusing point, about 2·6 Ohms; and the current to fire a charge through it, ·32 Veber.

The wire used in the unfortunate experiment was, as I have said, of No. 16, B.W.G. I have measured the resistance of the length of wire actually used, and found it to be ·69 Ohm. Its length was $87\frac{1}{2}$ yards. According to this, the length of one Ohm resistance was 126·8 yards, or at the rate of about $13\frac{3}{4}$ Ohms per mile. This is the value which, for obvious reasons, I have adopted in this paper.

Assuming that the fuse used was No. 12, and the electromotive force to be as given by Everett, we have, for the firing current:—

$$\text{Total resistance in circuit} = \frac{.564}{\cdot 75} = \cdot 752 \text{ Ohm},$$

and this resistance consists solely of the fuse and the wire, that of the cell being nothing.

If the resistance of the platinum wire did not increase as the temperature of the wire increases, we should have—

Total resistance of circuit ...	... ...	·752 Ohm
Resistance of fuse when cold	... ...	·325 „
Leaving for resistance of the conducting wire		·427 „

which resistance = about 54 yards.

This is the greatest length of wire through which the current would fire the charge, on the supposition that the resistance of the wire is constant.

Through that distance the charge might not be expected to explode, but I could not assert that it would not explode. The current would probably heat the wire, though perhaps but slowly; the resistance of the wire would increase with the temperature, and this increase would most probably reduce the current to a strength at which it would not fire the charge. It is in the first rush of the current through the conductor that the danger would lie, for that first rush might raise the wire to a temperature considerably higher than that at which it could maintain it, and that higher temperature might be dangerous.

From Bloxom's *Chemistry*, third edition, page 503, I find that gun-cotton, which is the material in a properly made fuse which is in contact with the platinum wire, and is first fired by it, "is more easily exploded than gunpowder. The latter requires a temperature of at least 600° F., whilst gun-cotton may explode at 277° F., and must explode at 400° F." It further appears that the average temperature at which gun-cotton explodes when in the condition most favourable to its rapid heating is about 300° F.; and this, it is important to note, is a temperature much nearer the lower than the higher of the two limits given.

According to the *Chatham Instructions in Military Engineering*, the resistance of the platinum wire increases ·07 per cent. per degree F. As its resistance at 60° F. is ·325, at 277° F. it would be—

$$\cdot 325 + \frac{\cdot 325 \times \cdot 07 \times 217}{100} = \cdot 374 \text{ Ohm}$$

And at 400° F. it would be—

$$\cdot 325 + \frac{\cdot 325 \times \cdot 07 \times 340}{100} = \cdot 402 \text{ Ohm}$$

For the lower of these resistances we have—

Total resistance of circuit	...	·752 Ohm
Resistance of fuse at 277° F.	...	·374 „
Resistance of wire	...	·378 „

which resistance = about 48 yards; and for the higher—

Total resistance of circuit	...	·752 Ohm
Resistance of fuse at 400° F.	...	·402 „
Resistance of wire	...	·350 „

which resistance = about $44\frac{1}{2}$ yards.

Through any length of wire considerably exceeding 48 yards, therefore, contact of the wire with the body of the vessel would be comparatively safe. Through all lengths of wire between 48 yards and $44\frac{1}{2}$ yards the charge might or might not explode, according to the quality of the gun-cotton. Through lengths less than $44\frac{1}{2}$ yards the charge certainly should explode.

Bearing in mind that the resistances of the best made wires and fuses will vary as the quality of the metal, the size of the wire, and, in the case of the fuse, as the lengths of the wire vary, it will be apparent that no sane person would for a moment trust his own life or the lives of others to the chance of a charge not exploding through any length of wire at all near the higher of the limits I have given.

Different results follow from using the more sensitive fuse, No. 13, and by taking the lower value for the electromotive force. The results are embodied in the following table:—

Electromotive Force.		No. of Fuse		Lengths of No. 16 wire between which explosion may be expected.		
·564	...	12	...	48 yards	—	$44\frac{1}{2}$ yards
·564	...	13	...	$65\frac{3}{4}$ „	—	54 „
·514	...	12	...	39 „	—	$35\frac{1}{2}$ „
·514	...	13	...	46 „	—	34 „

For lengths exceeding the greater lengths the charge may not be expected to explode; for lengths shorter than the less the charge should explode.

In such a circuit as that in question the fuse of itself forms so large a portion of the total resistance of the circuit that a slight variation in its resistance has a very appreciable effect. The resistance of the fuse when cold is equal to that of about 41 yards of No. 16 wire. If the bridge of the fuse consisted of ·2 inch instead of ·3 inch of platinum wire, its resistance would be about ·1 Ohm less. Hence, to maintain the same strength of current, an addition of ·1 Ohm, or about $12\frac{1}{2}$ yards, might be made in the length of the firing line. But as a less current would fire such a fuse, more than $12\frac{1}{2}$ yards might be added without decreasing the efficiency of the current.

It may be thought that in these calculations I have been unnecessarily particular, as, for instance, in allowing for differences of temperature, &c.; but I have thought it best to be precise. There will always be a margin of uncertainty in such calculations, for the constants used can only be regarded as approximately correct; but I have been anxious not to add to that uncertainty by any laxness in the use I have made of the constants.

Doubtless the Torpedo Inquiry Board has good reasons for not having tested the foregoing purely theoretical considerations by a series of experiments, which would have decided the question of the strength of the sea-cell current. Perhaps it may even yet adopt that course.

In the meantime, I proceed to give the result of some experiments recently made by Messrs. Geo. S. Caldwell and Geo. Smibert, both of the Post and Telegraph Department, and both well known as practical and scientific electricians. Mr. Caldwell's previous experience as an electrician had convinced him that, under certain circumstances, the current from a sea-cell was of considerable magnitude. Hence, from the time of the accident he suspected, and he is the only person I know who from the first did suspect, that the accident might have been caused by a sea-cell current. Instead, therefore, of regarding as decisive the negative results of certain experiments we have heard of through the daily papers, these gentlemen resolved to test the question for themselves. They did not intend to publish the results, but, at my request, have kindly placed them at my disposal.

The experiments were made from on board R.M.S. "Malwa," as she lay alongside the Railway Pier at Williamstown. A zinc plate, 7 feet by 3 feet, was lowered over the side of the vessel, well clear of the hull; and, to complete the circuit, a small portion of the main rail of the ship was scraped clean of paint and rust, and touched with the end of the wire. After some preliminary tests with the galvanometer, eight fuses were experimented on, with the following results:—

1. Exploded on first contact through about 8 yards of wire.

2. Exploded through the same length, but only after a considerably longer contact, showing a decided difference in the sensitiveness of the fuses.

3. Exploded through 10 yards.

4. Exploded through about 14 yards.
5. Exploded through about 24 yards.
6. Exploded through about 41 yards at moment of contact, showing that the fuse was of great comparative sensitiveness.
7. Exploded through about 21 yards.
8. Exploded through about 17 yards, but only after long contact.

By actual measurement the resistance of the wire used gave 1 Ohm to 175 yards. The proportion of 175 to 126·8 is very nearly as 7 to 5. If, therefore, we take five-sevenths of the length of wire used by Messrs. Caldwell and Smibert, we get very nearly the corresponding lengths of wire of the same resistance as that used in the Queenscliff experiment.

The fuses used were sent out to the colony some years ago for use in the Torpedo Corps, and, it is to be presumed, were manufactured with proper care in the Government workshops at home. By measurement, I find the resistance of them to vary from about ·6 to about ·7 Ohm; but I cannot say what current is supposed to be sufficient to fire them, as I do not know the size, &c., of the wire employed. I can only say that they were regulation fuses, for use in torpedo work, and that they were not "made for the occasion."

From these experiments, in connection with some tests with the galvanometer, Mr. Caldwell suspected that in the hull of the "Cerberus" there was a more potent metal exposed than iron, and he concluded that, possibly, there were some copper surfaces connected with the vessel exposed to the action of salt water. He ascertained that a sheet of zinc, 7 feet by 3 feet, in conjunction with a sheet of copper 18 inches square, will unfailingly fire these regulation fuses through short lengths, say about 12 feet of the wire usually employed.

My calculations have reference to the power of an iron and zinc sea-cell; but the presence of an exposed surface of copper in the bottom of the iron vessel would, undoubtedly, increase the electromotive force of the cell. Now, it is a fact that in the bottom of the "Cerberus" there is an amount of copper surface exposed to the action of the sea-water, and the same may be said of R.M.S. "Malwa."

With reference to the experiments from the "Malwa," however, the consideration must not be lost sight of that in the sea-water just within the entrance at the Heads there is a much larger proportion of salt than there is in the water off the Williamstown Railway Pier. With the same metals, therefore, the electromotive force of the cell would be less at Williamstown than it would be at Queenscliff.

I would invite your attention to the differences in the fuses used. They are supposed, and certainly were intended, to be uniform, and yet we find them to vary greatly in point of sensitiveness; and this naturally leads me to repeat the remark that some degree of uncertainty attaches to the constants that enter into calculations like the present. Thus, I have had to use two values for the electromotive force of the cell, of which values both cannot, and neither may be, correct, for the true value may lie between the two. These two values, as well as the other constants I have made use of, must be regarded as the mean or average values, resulting from a number of measurements. Hence, a current that will explode one fuse will fail to explode another supposed to be similar; and if theory shows that a certain kind of fuse should explode through a certain length of wire, one fuse may explode through a greater while another may fail to explode through a less length.

Thus the foregoing calculations point to a doubtful and dangerous region between the positively will and the positively will not, a region in which a fuse may or may not explode, according to circumstances not fully known to us, and which, therefore, cannot enter into our calculations; and if it be an object to avoid an explosion, we should make it a point to keep as far from this region as practicable.

This is fully recognised in the instructions for guidance in torpedo operations. If it be an object to make an explosion certain, it is usual to provide a current double that which theory shows to be just sufficient. If, on the other hand, it is necessary to send a current through a fuse without exploding it, as in certain testing operations, which I need not particularise, it is important that the current should be so small as to preclude danger of an explosion. And as bearing on the subject of the late accident, it is of interest to note what is considered as the limit of danger. The *Submarine Mining Drill Book* forbids the use of a larger current for testing than ·3 Veber; any current exceeding that, is presumed to be more or less dangerous. A sea-cell current between the hull of an iron vessel and a large zinc plate through the wire used at Queenscliff and a No. 12 fuse would be from ·5 to ·55 Veber.

Viewed in the light of the foregoing remarks, the experiments of Messrs. Caldwell and Smibert may, I think, be fairly regarded as confirming the conclusions I had come to from considerations purely theoretical.

They certainly prove that, notwithstanding assertions to the contrary, a sea-cell consisting of an ironclad like the "Cerberus" and a large zinc case with short lengths of No. 16 wire does produce a heating current through a regulation fuse.

It may be asked how certain experiments carried out in this and in an adjoining colony, and which did not produce like results, are to be explained. For my own part, I may say that I do not feel called upon to explain them. I have given the results of experiments made by persons of known experience and skill under circumstances sufficiently explained; but I am not called upon to explain the cause of the failure of experiments all the circumstances of which I do not know. Moreover, this is one of those cases in which one well-authenticated experiment that succeeds is of more importance, as a warning of danger, than are fifty that fail.

Whatever may have been the cause of the accident, it seems clear that in the Queenscliff experiment the experimenters were treading on dangerous ground. All that was necessary to produce a dangerous current was an accidental contact between the end of the wire and the iron body of the vessel. And the fact that the position was one of danger would remain, even though it could be proved that the explosion occurred through the presence of dynamite in the charge, or from some other cause at present, perhaps, unsuspected.

The conclusions I deduce from the foregoing remarks may be briefly summarised as follows:—

It is not proved that the explosion was caused by a sea-cell current. There is no proof that the circuit was completed; and neither by theoretical calculation, nor as yet by experiment, has it been shown that a sea-cell current would explode a fuse through such a length of No. 16 wire as that made use of.

But whatever may have been the cause of the accident, and it will probably never be known, it seems clear that the sea-cell current was a source of danger in the experiment. It would still have been so if the accident had not taken place; though, in that case, the danger would have remained unsuspected. I have not before seen attention called to this danger; but I consider it so great that any officer in charge of an ironclad who would allow of experiments being made from on board with charges in zinc cases would incur a very heavy responsibility.

I do not concur in the blame that in some quarters has been thrown on the officer conducting the Queenscliff experiments for using a zinc case for the charge; and, in simple justice to that gentleman, I may state that every person of any knowledge of electricity to whom I have spoken on the subject, including some of considerable experience in torpedo experiments, has candidly admitted that he would not have suspected danger from the iron, zinc, and sea-water combination.

But if it would not have occurred to any of those electricians, it may escape the notice of other gentlemen conducting similar experiments at home or elsewhere. It is for that reason I am desirous that the power of the sea-cell current, under certain circumstances, should be properly recognised. I may have over-estimated the danger, and some of the constants I have used may require correction. That of the firing current, for instance, may be too low; but if there be danger at all, its presence should be known and guarded against. It is better in torpedo operations to keep well on the safe side than, by misplaced confidence, to endanger, and perhaps sacrifice, valuable human lives.
